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Carbon Footprint Assessment and Pathway to Carbon Neutrality in a Higher Educational Institute: A Case Study of the Alpine Institute of Management and Technology, Dehradun, India

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Abstract: The building sector is a major contributor to global greenhouse gas (GHG) emissions, and higher education institutions, with their diverse operational activities, represent a significant but underexplored subsector for carbon accounting. This study quantifies the carbon footprint of the Alpine Institute of Management and Technology, Dehradun (Uttarakhand, India), over four calendar years (2022-2025) using a bottom-up Life Cycle Assessment (LCA) approach aligned with ISO 14064-1 and the GHG Protocol Corporate Standard. Emission sources were classified into Scope 1 (static and mobile combustion), Scope 2 (purchased electricity), and Scope 3 (employee commuting, waste disposal, water consumption, and paper/stationery use), with human respiration quantified separately as a supplementary source. Total institutional emissions under Scopes 1-3 were found to be 56,351.77 kg CO_2-eq (2022), 60,131.82 kg CO_2-eq (2023), 62,168.00 kg CO_2-eq (2024) and 59,604.84 kg CO2-eq (2025), with purchased electricity (Scope 2) the dominant contributor at 41-44% of the total in every year studied, followed by Scope 1 combustion sources (38-40%) and Scope 3 activities (18-20%). Inclusion of human respiration more than doubled the reported footprint to a range of 126,536.77-134,468.84 kg CO_2-eq, accounting for 55-58% of total emissions across the study period. A tree census conducted within the institutional boundary and evaluated using allometric biomass equations yielded an existing carbon sequestration potential of 73,332.00 kg CO_2-eq, which exceeds the Scope 1-3 emissions for every year studied, indicating that the campus already functions as a carbon-neutral facility when respiration is excluded from the accounting boundary. When respiration is included, the sequestration deficit indicates a need for additional carbon sinks and offsets, for which rooftop solar photovoltaic potential (2,625 m^2 of available roof area), rainwater harvesting, and afforestation initiatives are identified and quantitatively assessed. These results provide a replicable, data-driven template for carbon accounting and neutrality planning in resource-constrained educational institutions and contribute empirical evidence toward Sustainable Development Goal 13 (Climate Action).
Keywords: carbon footprint; carbon neutrality; GHG Protocol; ISO 14064-1; life cycle assessment; educational institute; carbon sequestration; Scope 1, 2, 3 emissions.

I. INTRODUCTION

Anthropogenic greenhouse gas (GHG) emissions are the principal driver of global warming, and the building sector alone is estimated to contribute nearly 39% of global GHG emissions, of which approximately 28% arises from operational energy use and 11% from embodied carbon in construction materials. The Global Status Report for Buildings and Construction (UNEP, COP27, 2022) recorded that the building sector accounted for more than 34% of global energy demand and roughly 37% of energy- and process-related CO_2 emissions in 2021, with this share projected to double by 2050 in the absence of decisive mitigation. The Paris Agreement (COP21, 2015) and subsequent IPCC assessments have established that limiting global warming to 1.5 degrees C above pre-industrial levels requires a rapid, quantifiable reduction pathway, formalised in corporate and institutional GHG accounting through the WRI/WBCSD GHG Protocol Corporate Standard, which classifies emissions into Scope 1 (direct), Scope 2 (indirect, purchased energy) and Scope 3 (other indirect) categories.

Within the building sector, higher education institutions constitute a distinctive operational typology: they combine residential (hostel), catering, transportation, laboratory, and administrative functions within a single, well-defined campus boundary, making them tractable subjects for comprehensive carbon accounting while also serving as visible platforms for climate leadership and student engagement. A growing body of international literature has applied Life Cycle Assessment (LCA) and the GHG Protocol Corporate Standard to university and college campuses; however, most existing studies exclude Scope 3 emissions from personal-vehicle commuting owing to data-collection difficulties, and none of the reviewed literature combines a bottom-up ISO 14064-1 inventory with an explicit accounting of human respiration as a supplementary emission source. This study addresses that gap through a multi-year (2022-2025), semester-resolved carbon footprint assessment of an AICTE-approved, multi-disciplinary institute in the Himalayan foothills, and couples the emissions inventory with an on-site carbon sequestration assessment and a set of quantified neutrality pathways. The specific objectives of this study are to: (i) identify and enumerate the sources of carbon emission within a defined institutional boundary over a nine-semester timeline; (ii) quantify emissions under Scope 1, Scope 2 and Scope 3 categories following the GHG Protocol Corporate Standard, using a bottom-up ISO 14064-1 methodology; (iii) determine the existing on-site carbon sequestration potential through a tree census and allometric biomass modelling; and (iv) propose and quantify additional carbon sinks and offsets required to achieve verified carbon neutrality, inclusive of human respiration.

II. LITERATURE REVIEW

A substantial body of research has applied Life Cycle Assessment (LCA) and the GHG Protocol Corporate Standard to institutional carbon accounting, with university campuses frequently used as case studies due to their well-defined boundaries. Foundational work by Kulkarni et al. (2019) developed a bottom-up LCA methodology and scope-wise conversion factors for an Indian institute, recommending renewable energy and waste reduction as key mitigation measures. Sangwan et al. (2018) found electricity responsible for nearly 70% of emissions at BITS Pilani, followed by transportation (16%) and food waste (10%). Robinson et al. (2018) reviewed six existing carbon-accounting methodologies and identified significant inconsistencies, calling for a universal standard. Kiehle et al. (2023) combined LCA with input-output analysis at the University of Oulu, again finding that electricity was dominant, with transport emissions falling by 20% since 2007.

Several studies extended this base across all three scopes. Sen et al. (2022) and Battistini et al. (2023) emphasized transparent reporting and stepwise methodologies for multi-campus assessment. Cano et al. (2023) and Adeyeye et al. (2023) jointly incorporated Scope 3 sources, such as business travel and procurement, using ISO 14064-1 and the GHG Protocol standards, while Gulcimen et al. (2023) broadened the scope further with Life Cycle Costing and Social LCA. Sudarshan et al. (2019) applied LCA specifically to educational buildings, recommending efficient design and low-carbon materials.

A parallel body of work addressed methodological and data-quality challenges. Pandey et al. (2011) compared LCA, input-output analysis, and emission-factor methods, while Wiche et al. (2022) highlighted persistent gaps in material data and embodied-carbon accounting. Klein-Banai and Theis (2013) and Cooper et al. (2023) confirmed energy consumption as the leading institutional driver of emissions, with transportation and food waste as secondary contributors. Fouladvand et al. (2023) extended similar findings to a non-academic institutional setting.

Building- and material-focused studies added further depth. Guo et al. (2023) found construction responsible for 45% of a building's lifetime emissions in China, with LEED Platinum buildings emitting up to 70% less carbon. Ropo et al. (2023) integrated embodied carbon and compensation costs into life-cycle cost optimization, while Gaarder et al. (2023) identified an optimal insulation thickness (5–20 cm) balancing embodied and operational emissions. Wilberforce et al. (2023) and C. Liu et al. (2023) reviewed net-zero building advantages and retrofit strategies, and K. Liu et al. (2022) compared major green-building rating systems, finding energy and materials the most heavily weighted criteria.

Carbon sink research is comparatively limited but growing. Sharma et al. (2021) applied allometric equations to estimate tree-species sequestration potential, and Wang et al. (2022) extended this to turfgrass systems. da Silva et al. (2023) and Mehta et al. (2022) documented institutional decarbonization pathways in practice, citing financial and regulatory barriers as key constraints.

Collectively, this literature confirms electricity as the dominant institutional source of emissions and validates bottom-up LCA under ISO 14064-1 as the most robust accounting approach. However, three gaps persist: Scope 3 emissions from personal-vehicle commuting are routinely excluded due to data limitations; carbon sinks and offsets are typically proposed in isolation rather than integrated into a balanced equation; and human respiration, though a quantifiable emission source on an occupied campus, remains absent from the GHG Protocol and from prior studies.

A. Research Gaps

Despite this substantial body of work, three gaps recur across the reviewed studies. First, Scope 3 emissions from personal vehicle commuting are excluded from nearly all institutional inventories because reliable activity data are difficult to obtain. Second, carbon sink and carbon offset strategies are generally proposed in isolation rather than integrated into a single balanced institutional equation. Third, human respiration, although a physiologically real and quantifiable source of CO_2 within an occupied educational campus, is not accounted for in the GHG Protocol Corporate Standard and is absent from the reviewed literature. The present study addresses all three gaps.

III. MATERIALS AND METHODS

A. Study Area and Temporal Boundary

The study boundary comprises the campus of the Alpine Institute of Management and Technology, Dehradun, Uttarakhand (30.3165 deg N, 77.8926 deg E; altitude approximately 640 m), an AICTE-approved, multi-disciplinary institute affiliated with HNB Garhwal Central University, situated on the banks of the Tons river within a humid subtropical climatic zone. The campus accommodates approximately 50 faculty/staff members and 350-400 students per semester across the administrative, engineering, pharmacy, and hostel blocks. The temporal boundary spans nine semesters (July-December 2021 through July-December 2025), enabling analysis of seasonal variation superimposed on the four full calendar years (2022-2025) reported here.

B. Carbon Accounting Approach

Carbon emissions were quantified using a bottom-up Life Cycle Assessment following ISO 14064-1, with activity data converted to CO_2-equivalent using conversion factors drawn from the GHG Protocol Corporate Standard, a joint initiative of the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The assessment proceeded through five sequential phases: (i) definition of the operational boundary and timeline; (ii) identification of emission sources under Scope 1, 2, and 3; (iii) collection and verification of activity data; (iv) calculation of the carbon footprint; and (v) identification and quantification of carbon sinks and offsets.

C. Emission Source Categories

Scope 1 (direct emissions) comprised static emissions from LPG combustion for cooking in the boys' hostel, girls' hostel, and college canteen, as well as mobile emissions from the institute-owned fleet (one petrol car and three diesel buses). Scope 2 (indirect emissions) comprised purchased grid electricity, metered separately, for the girls' hostel, boys' hostel, and three institutional meters. Scope 3 (other indirect emissions) comprised employee and student commuting by personal vehicle, solid-waste generation, water consumption, and paper/stationery use. In addition, human respiration was quantified as a supplementary, non-Protocol source using semester-wise headcount data for staff and students. All activity data were sourced from hostel superintendent records, vehicle ledger books, State Electricity Board and Jal Sansthan utility bills, canteen and stock register entries, and a staff self-report survey on commuting, with cross-verification by department representatives.

The general conversion relationship applied to each activity category is:

$$CO_2\text{-equivalent} = \text{Activity Data} \times \text{Carbon Conversion Factor (CCF)}$$

D. Carbon Sequestration Assessment

On-site carbon sequestration potential was assessed through a tree census recording species, common name, and count for all trees and shrubs within the operational boundary, followed by measurement of stem diameter at 1.37 m height (D). Above-ground biomass (AGB) was estimated using the allometric equation applicable to areas receiving less than 1,500 mm annual rainfall (consistent with the study site's approximately 1,200 mm rainfall):

$$AGB = 34.4703 - 8.0671D + 0.6589D^2 \text{ (kg)}$$

Below-ground biomass (BGB) was taken as 15% of AGB, total biomass (TB) as the sum of AGB and BGB, and the carbon dioxide equivalent sequestered was calculated assuming 50% of total biomass is stored as carbon, converted to CO_2-equivalent using the molecular weight ratio of CO_2 to carbon (44/12):

$$CO_2 \text{ (eq.)} = 0.5 \times TB \times (44/12)$$

E. Carbon Sink and Offset Identification

Prospective additional carbon sinks and offsets were identified through a site audit of available rooftop area suitable for solar photovoltaic installation, assessment of rainwater-harvesting potential, and documentation of an institute-led afforestation programme (Sal and Deodar cedar plantation) undertaken in partnership with the state forest department.

IV. RESULTS AND DISCUSSION

A. Scope-wise Emission Inventory

Table 2 presents the consolidated, scope-wise carbon emission inventory for the Alpine Institute campus for calendar years 2022-2025, including human respiration as a supplementary category.

Table 2. Consolidated scope-wise carbon emission inventory, 2022-2025 (kg CO_2-eq)

Scope / Category	2022 (kg)	2023 (kg)	2024 (kg)	2025 (kg)
Scope 1 - Static (LPG)	12,240.74	13,343.70	13,992.50	13,257.19
Scope 1 - Mobile (fleet fuel)	10,264.40	9,152.20	9,595.00	9,975.00
Scope 2 - Electricity	23,620.80	26,549.00	26,921.00	24,497.40
Scope 3 - Employee commuting	7,646.00	8,408.40	9,055.00	9,101.40
Scope 3 - Waste disposal	1,640.00	1,637.52	1,531.00	1,543.44
Scope 3 - Water consumption	694.48	671.83	667.00	820.41
Scope 3 - Paper/stationery	245.35	369.17	406.47	410.00
Subtotal (Scope 1-3)	56,351.77	60,131.82	62,168.00	59,604.84
Human respiration	70,185.00	73,993.47	73,993.40	74,864.00
Total (incl. respiration)	126,536.77	134,125.29	127,116.00	134,468.84

Considering only the three GHG Protocol scopes, total institutional emissions ranged from 56,351.77 kg CO_2-eq in 2022 to a peak of 62,168.00 kg CO_2-eq in 2024, before declining slightly to 59,604.84 kg CO2-eq in 2025. Scope 2 (purchased electricity) was the dominant contributor in every year, accounting for 42% (2022), 44% (2023), 43% (2024), and 41% (2025) of Scope 1-3 emissions, consistent with the Himalayan foothill climate of the study site, where heating, lighting, and hostel electricity demand rise sharply in winter months. Scope 1 (static and mobile combustion) was the second-largest category, contributing 40%, 38%, 38% and 39% across the same four years, while Scope 3 activities contributed the smallest but steadily increasing share, from 18% in 2022 to 20% in 2025, driven primarily by rising employee and student commuting distances.

When human respiration is included, total institutional carbon emissions more than double, ranging from 126,536.77 kg CO_2-eq (2022) to 134,468.84 kg CO_2-eq (2025), with respiration alone contributing 55% (2022), 55.16% (2023), 58% (2024), and 56% (2025) of the total. This finding underscores that respiration, although excluded from the GHG Protocol Corporate Standard, is quantitatively the single largest carbon source associated with an occupied educational campus and therefore constitutes an essential consideration for any institution pursuing a rigorously verified claim of carbon neutrality.

B. Carbon Sequestration Potential

The tree census recorded 46 individual trees across 13 species within the campus boundary (Table 3). Using the allometric biomass equations, the total existing sequestration potential was calculated to be 73,332.00 kg CO_2-eq. Red Cedar (Toon, Toona ciliata) contributed the largest individual-species sequestration (35,938.64 kg CO_2-eq from 4 trees, reflecting large stem diameter), followed by Mango (Mangifera indica) at 18,419.79 kg CO_2-eq. In comparison, Lemon (Citrus limon) contributed the smallest share (155.75 kg CO_2-eq).

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Table 3. Tree census and estimated carbon sequestration potential within the institutional boundary

Species	No.	AGB (kg)	BGB (kg)	Total Biomass (kg)	CO_2-eq (kg)
Red Cedar (Toon)	4	17,030.52	2,554.57	19,585.09	35,938.64
Mango	4	8,728.54	1,309.28	10,038.00	18,419.79
Litchi	3	2,801.36	420.20	3,221.56	5,911.56
Amaltas	2	2,044.38	306.65	2,351.03	4,314.14
Eucalyptus	4	1,340.68	201.10	1,541.78	2,829.16
Indian Blackberry	3	1,072.24	160.83	1,233.07	2,262.68
White Cedar	3	518.10	77.69	595.65	1,093.01
Ashoka	6	211.44	31.71	243.15	446.18
Indian Soapberry	2	347.34	52.10	399.44	732.97
Pomegranate	3	282.50	42.40	324.87	596.13
Palm	8	196.79	29.51	226.30	415.26
Indian Gooseberry	2	102.71	15.40	118.11	216.73
Lemon	2	73.81	11.07	84.88	155.75
Total	46	-	-	-	73,332.00

C. Emission-Sequestration Balance

Comparing the Scope 1-3 emissions inventory against the existing sequestration potential (Figure, described textually as the study did not require a rendered chart for this comparison) indicates that on-site tree cover already exceeds annual Scope 1-3 emissions in every year studied (by margins of 16,980 kg in 2022 to 13,727 kg in 2025), meaning the campus can be classified as carbon-neutral when the accounting boundary follows the GHG Protocol Corporate Standard strictly. However, once human respiration is included, existing sequestration meets only 54-58% of total annual emissions, leaving an unmet sequestration demand of approximately 53,200-61,100 kg CO2-eq per year that must be addressed through additional sinks or offsets to achieve neutrality under a more comprehensive accounting boundary.

D. Proposed Additional Sinks and Offsets

A rooftop audit identified 2,625 m^2 of usable roof area across five institutional blocks (Table 4) suitable for solar photovoltaic deployment. Renewable electricity generated on this footprint would directly displace demand for Scope 2 grid electricity, the single largest emissions category identified in this study. At the same time, surplus generation could be exported to the state grid as a quantifiable carbon offset.

Table 4. Available rooftop area for solar photovoltaic installation, by institutional block.

Block	Rooftop Area (sqm)
Administrative Block	450
ECE, Pharmacy, and Computer Engineering Block	800
Civil Engineering Block	500
Girls' Hostel Building	400
Boys' Hostel	475
Total	2,625

Complementary interventions identified include activation of an existing but non-operational rainwater-harvesting system to offset Scope 3 water-related emissions, installation of water-efficient fixtures and star-rated appliances, adoption of passive design strategies such as solar-chimney ventilation and maximized day lighting to reduce Scope 2 demand, and an institute-run afforestation programme (Sal and red cedar) undertaken with the state forest department and managed by a dedicated student Eco-club, which will incrementally increase the sequestration base documented in Table 3 over the coming years.

V. CONCLUSION

This study developed and applied a bottom-up, ISO 14064-1-aligned carbon accounting framework, using the GHG Protocol Corporate Standard conversion factors, to quantify the multi-year carbon footprint of a Himalayan foothill higher education institute. Scope 1-3 emissions ranged from 56,351.77 to 62,168.00 kg CO_2-eq over 2022-2025, with purchased electricity (Scope 2) consistently the dominant source (41-44%), followed by direct combustion (Scope 1, 38-40%) and indirect activities (Scope 3, 18-20%).

The inclusion of human respiration, a source outside the formal GHG Protocol boundary but physiologically significant on an occupied campus, more than doubled reported emissions to 126,536.77-134,468.84 kg CO_2-eq and accounted for 55-58% of the total, the single largest identified source in this study.

A campus tree census combined with allometric biomass modelling quantified an existing sequestration potential of 73,332.00 kg CO_2-eq, sufficient to offset Scope 1-3 emissions in every year studied and supporting a classification of the institute as carbon-neutral under the standard Protocol boundary when respiration is included, however, a substantial sequestration deficit remains, which the study addresses through quantified proposals for rooftop solar photovoltaics (2,625 m^2 available area), rainwater harvesting, and an active afforestation and offset programme.

These findings demonstrate that data-driven, semester-resolved carbon accounting is achievable in a resource-constrained institutional setting using routinely available utility, ledger, and administrative records, and that the resulting inventory can directly inform prioritised, quantified decarbonisation investment (led by electricity-demand reduction and on-site renewable generation) in support of Sustainable Development Goal 13.

VI. FUTURE SCOPE

Future work should extend the Scope 3 boundary to include laboratory chemical use, embodied carbon from ongoing construction activity, and turf grass/lawn carbon sequestration, and should pursue continuous, real-time monitoring (e.g., smart electricity sub-metering) to replace the periodic utility-bill-based data collection used in this study, thereby improving temporal resolution and reducing reliance on manual verification.

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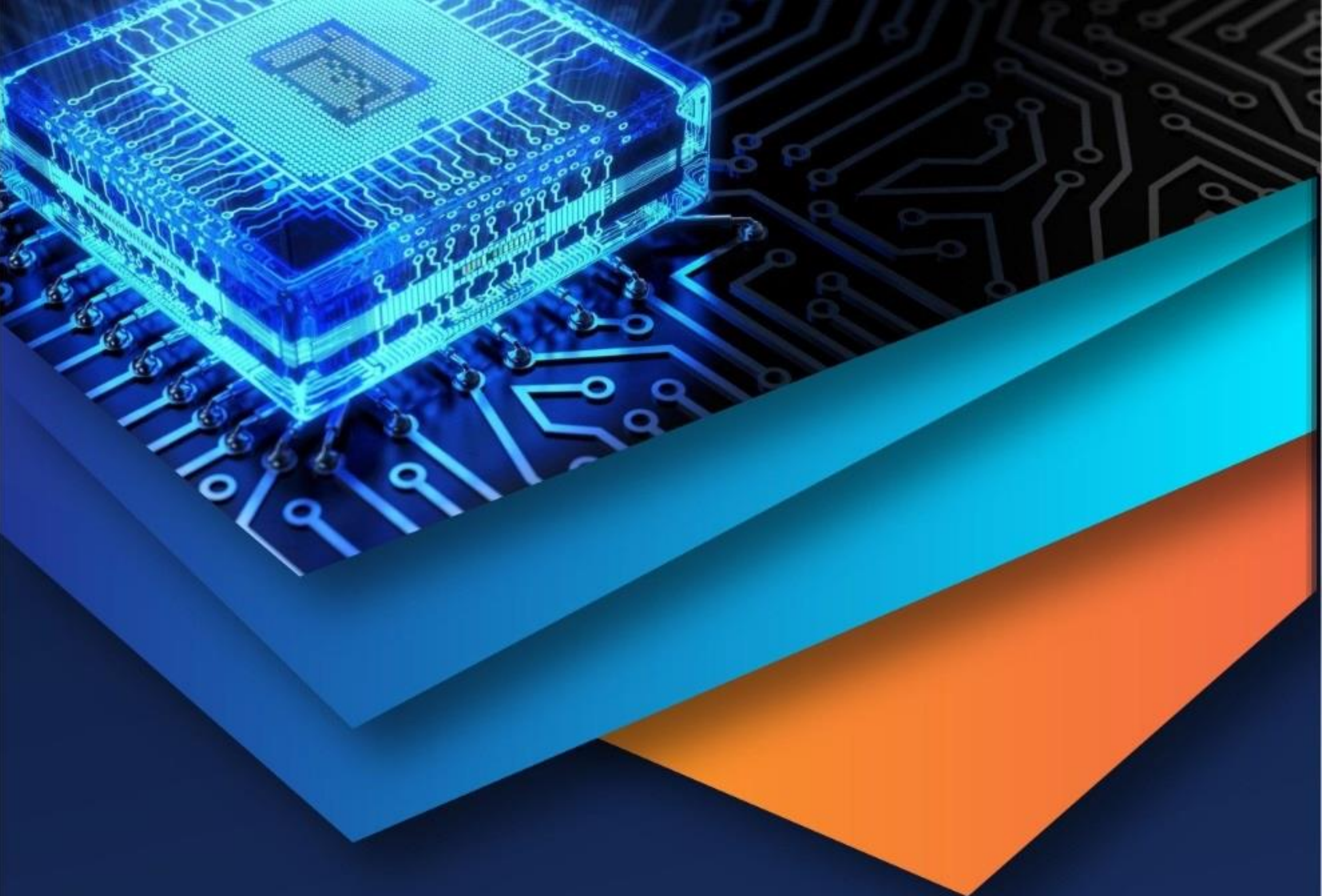

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